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Virtual Environments for Corporate Education: Employee Learning and Solutions

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Chapter 6

Virtual Learning Environments for Manufacturing

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ABSTRACT

Since the advent of globalization, the manufacturing industry has been subject to continuous pressure of competition. Products have to be developed faster than before, with equivalent or higher quality, and at significantly lower cost. Whilst modern manufacturing systems provide the technological edge to meet these challenges, one tends to forget that education and training of the workforce also has to be kept up-to-date. Only a workforce that is familiar with the latest advancements in the manufacturing sector and well trained in the use of state-of-the-art technology and tools will be able to effectively face the competition. Although fundamental education and training may have been provided by the academic sector, employees need to continue developing their professional skills and competencies throughout their entire professional life. One potential approach to education and training of engineers in the manufacturing sector is the utilization of Virtual Learning Environments (VLEs). Such VLEs are currently widely used for fundamental engineering education in academia, but they also hold a huge potential for successful deployment in distributed corporate settings. Manufacturing-related VLEs may provide employees at all sites of a company across the globe with an affordable and safe environment for education and training, ranging from the fundamentals of modern manufacturing to expert level training in manufacturing process planning and simulation, without any need for, or cost of, physical equipment, materials, tools or travel. In this chapter the authors discuss how Virtual Learning Environments (VLEs) for manufacturing-related education and training can be utilized in the corporate sector.

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INTRODUCTION

In his bestselling book *The World is Flat* author Thomas L. Friedman (Friedman, 2006) points out that “*Globalization has collapsed time and distance and raised the notion that someone anywhere on earth can do your job, more cheaply*”. This certainly applies to the manufacturing industry, which is increasingly becoming a commodity. In recent years the manufacturing industry has been strongly impacted by globalization, which has resulted in increased global competition. This manufacturing competition has acted as a driving force for the application of new, related technologies in industry. In order to sustain their competitiveness, companies need to be able to adapt quickly to rapidly changing conditions of both the market and their competitors at reduced cost and at least equivalent or better quality.

While modern manufacturing systems may provide the technological means to face the above challenges, one also needs to bear in mind that the workforce which utilizes these systems has to keep up with the latest advances through education and training. Current students, i.e., the workforce of tomorrow, usually receive fundamental manufacturing-related education and basic training through engineering degree programs. For more senior employees this education and training often has to be acquired through participation in continuous professional development programs. What is missing today is an effective means to provide employees of manufacturing companies with continuous education and training opportunities on-the-job, within their corporations, and around the globe. An interesting question to explore with regard to manufacturing-related education and training is: “*Where are we now, and where are we heading?*”

While some universities may be able to expose their students to the latest manufacturing systems and technologies, others may not be that fortunate, due to lack of financial resources. For the latter, alternative avenues for providing their

students with equivalent education and training have to be developed. A potential response to this call is the adoption of advanced computer technology to facilitate the provision of flexible manufacturing-related education and training programs. To date many studies have shown that the use of computers for teaching and training purposes is feasible and rapidly becoming an integral part of the general learning process. It has also been confirmed that recent advances in information and communications technologies have positively influenced and changed the economics of engineering education (Hashemipour et al., 2009). These advances can be exploited as a powerful vehicle for educators to develop IT-enabled learning environments for manufacturing that utilize simulation, automated data acquisition, remote control of instruments, rapid data analysis, and video presentations. Computer applications related to simulating manufacturing processes have shaped a field which is currently known as Virtual Manufacturing (VM).

An additional Computer Science field that increasingly plays an important role in Virtual Manufacturing, as well as associated educational activities, is Virtual Reality (VR). VR environments are synthetic environments, which provide a sense of reality and an impression of ‘being there’. They have been increasingly employed in various design and manufacturing applications, including computer-aided design (CAD), tel-erobotics, assembly planning, and manufacturing system visualization and simulation. VR shows great potential for analyzing and investigating manufacturing processes prior to producing any physical artifacts. As a result, such environments help reduce operational expenses through reducing the number of physical prototypes and mistakes made. With regard to training the manufacturing work force, many studies have emphasized the potential of VR technology for education and training purposes. Empirical data has been collected on the relative success of VR in terms of instructional effectiveness, as well as the transfer of

skills to the real world (Hashemipour et al., 2009). The utilization of Virtual Learning Environments (VLEs) in manufacturing is considered to be one of the most promising ways of providing a safe, cost-effective, and flexible environment for training and education in manufacturing.

Although such VLEs are more common, and more widely used, for fundamental engineering education in academia, they also have a huge potential for successful deployment in distributed corporate settings. Through such VLEs employees at all sites of a company across the world may be provided with an affordable and safe environment for education and training, ranging from the fundamentals of modern manufacturing to expert level training in manufacturing process planning and simulation, without any need for physical equipment, materials, tools, or travel. However, as discussed earlier, such Virtual Learning Environments for Manufacturing are currently more predominant in academic settings and not yet readily available for industrial settings. Hence much remains to be done to replicate their successful implementation and utilization in the arena of corporate education.

This chapter presents a review of the current state of, and developments in, both virtual manufacturing and associated Virtual Learning Environments for manufacturing-related education and training. In addition to technological realization aspects, infrastructure and equipment, the authors focus on educational paradigms and instructional techniques required to implement and utilize such Virtual Learning Environments both effectively and efficiently. Key differences between academic and corporate settings are discussed, and guidelines for the development and implementation of Virtual Learning Environments for manufacturing-related education and training in distributed corporate settings are proposed.

VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

It is difficult to define the term Virtual Reality (VR) in a precise manner because it is often used in different contexts. A very general definition was given by Aukstakalnis and Blatner (1992): "Virtual Reality is a way for humans to visualize, manipulate and interact with computers and extremely complex data." However, many other definitions can be found in literature, for example, Manetta and Blade (1995) define VR as: "A computer system used to create an artificial world in which the user has the impression of being in that world and with the ability to navigate through the world and manipulate objects in the world". Similarly, Sherman and Judkins (1992) offer: "VR allows you to explore a computer generated world by actually being in it."

In this chapter we leverage the above definitions of VR and define a Virtual Environment (VE) as "a computer graphic system that allows a user to act in a synthetic, computer generated interactive 3D world". In other words, a simple VE is a computer system, which generates a virtual 3D environment with which a user can interact and receive real-time feedback (Normand et al., 1999). In contrast to conventional visualization systems, a VE is an interactive virtual image displayed in such a way that a user may become an active part of a rendered scene. Most VR/VE system configurations fall into three main categories and each category can be ranked by the sense of immersion, or degree of presence, it provides. These categories are: fully-immersive system, semi-immersive projection system and non-immersive (desktop) systems (Mujber et al., 2004). A comparison is presented in Table 1.

Fully-immersive VR systems provide a feeling of depth which is mainly created by techniques such

Table 1. Types of VR Systems (adapted from Mujber et al., 2004)

VR System	Fully Immersive VR	Semi-Immersive VR	Non-Immersive VR
Input Devices	Data Gloves and Voice Commands	Joystick, Spaceballs, Data Gloves	Mouse, Keyboard, Joystick, Spaceball
Output Devices	Head Mounted Display, CAVE	Large Screen Monitor or Projection Systems	Standard Monitor
Resolution	Low-Medium	High	High
Sense on Immersion	High	Medium-High	Low
Interaction	High	Medium	Low
Cost	Very Expensive	Expensive	Lowest

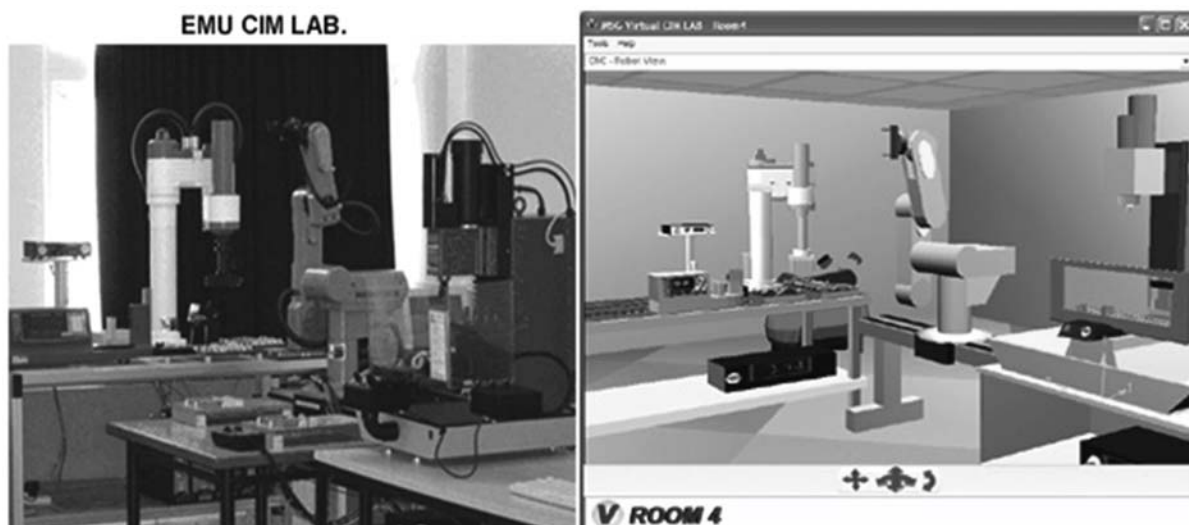
as head mounted display (HMD), Stereoscope Projection and Retinal Projection. In recent years advancements in computer technology and animated Computer Aided Design (CAD) have made it possible for VR technology to be ported down to personal computer platforms as semi-immersive and non-immersive (Desktop-VR) systems and hence provide the possibility of harnessing immersive and interactive environments (Figure 1).

A 3D virtual world can be displayed on a conventional desktop monitor, without use of any specialized movement tracking equipment,

through desktop-based virtual reality systems. For instance, many modern computer games, using various triggers, responsive characters and other such interactive devices, make the user feel as if they were in the virtual world. A common criticism of this form of immersion is that there is no sense of peripheral vision, limiting the user's ability to know what is happening around them (Methods of virtual reality, 2008). The operator may interact with the virtual world through a mouse, keyboard or three-dimensional (3D) trackers.

Desktop VR systems play an increasingly important role in the commercial world, offering an affordable solution that displays a virtual

Figure 1. A desktop VR system



environment on a conventional desktop PC in a non-immersive manner (Rooks, 1999). In many cases Desktop-VR is replacing traditional techniques of communicating and presenting due to its low cost and portability. In addition, Desktop VR allows for providing the user with interactive, real-time, three-dimensional visualization of almost any environment or scenario (Tait, 1998). As the technologies to support VR evolve, VE applications become literally unlimited and the benefits of VR are widely recognized by scientists and engineers working in many different fields, including natural sciences, surgery, architectural modeling and engineering, as well as training and education. It is considered that VR will help to reshape the interface between humans and information technology by offering new ways for the communication of information, the visualization of processes and the creative expression of ideas.

VIRTUAL ENVIRONMENTS IN EDUCATION

“Understanding focuses on application and knowledge-in-action offers the best potential for knowledge transfer, the creative application of knowledge, and the construction of new knowledge” (Chee, 2001).

In some areas of education, such as in engineering, it is often desirable for students and trainees to obtain a great deal of practice, which results in a robust understanding of the subject matter. Unfortunately, this is not always possible due to lack of resources in terms of up-to-date equipment, laboratory space, personnel, and maintenance. As stated previously, one potential approach to improving experience-based education is through the utilization of so-called Virtual Environments (VEs). Studies have emphasized the great potential of VEs for use in education and training at all the levels, for example Tan and Francis (1997)

showed that it is possible to use VEs as a training tool, especially in the use of complicated and potentially dangerous equipment.

Ong and Mannan (2004) state that VR interfaces have the potential to complement existing approaches in education. VEs simultaneously provide learners with 3D visualization, multiple perspectives and frames-of-reference and visual and audio feedback. Put simply, careful design and implementation of VR applications can create a profound sense of motivation and concentration resulting in a deep insight into, and mastery of, complex materials. While such VEs are more common and more widely used, for fundamental engineering education in academia, they also have a huge potential for successful deployment in distributed corporate settings. In this way employees at all sites of a company across the world may be provided with an affordable and safe environment for education and training, ranging from the fundamentals of modern manufacturing to expert level training in manufacturing process planning and simulation, without any need for physical equipment, materials, tools, or travel.

The growing literature on VE-based education shows that its exploitation in a wide variety of fields is a very promising approach in terms of both effectiveness and the reduction of costs. Many successful implementations of VEs in education and training have been reported. El-Mounayri et al. (2005) summarized some of the recent VE-based training and education activities as follows: *“Training for operation of engineering facilities, CNC manufacturing machines, vehicle driving, piloting, traffic and flight control, maintenance simulators, medical procedures training, and military operations training.”*

Advantages of virtual environments in education include:

- Provision of a safe and flexible learning and teaching environment.
- A sense of ‘being there’, so that trainees are free to develop solutions to ‘what if?’ scenarios.

- Opportunities to experience operating complex and expensive equipment in a safe and cost-effective way.
- Increased productivity in learning by higher retention and quicker comprehension.
- Opportunities for intuitive learning by doing.
- Fewer restrictions in the number of trainees.
- Less geographic and language barriers in the case of distance learning.

VIRTUAL MANUFACTURING ENVIRONMENTS

In recent years competition has acted as a driving force for the application of new technologies in the manufacturing industry. Successful companies must be able to adapt quickly to rapidly changing conditions of both the market and their competitors within a shorter lead time and at a lower cost.

As a result, there is an increased need for educators to incorporate the latest manufacturing-related approaches, processes and tools into their programs. Graduating engineers and other participating trainees entering the work force must be aware of the latest advancements in the field and trained in using the latest tools in order to help their companies face the global competition and sustain their competitiveness.

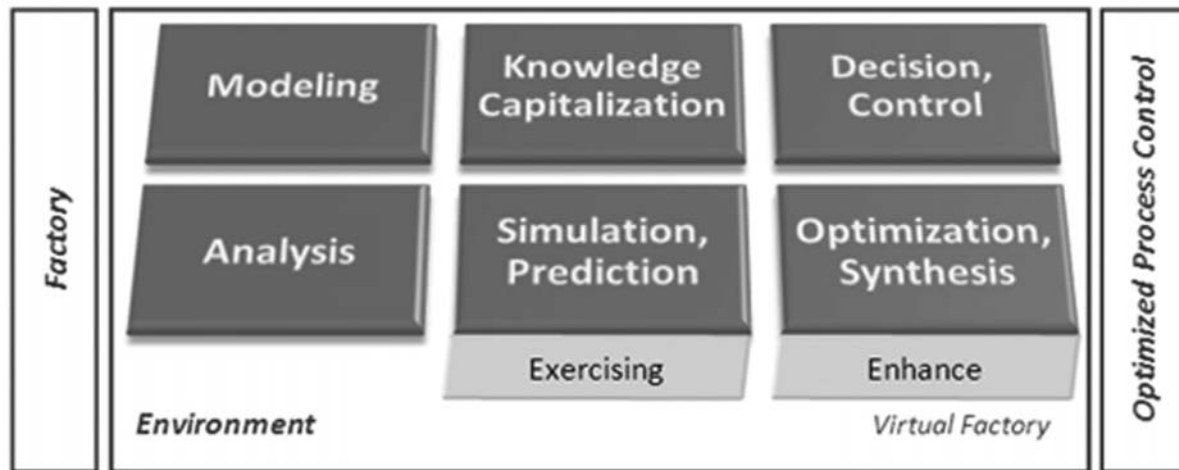
The term Virtual Manufacturing (or VM) is now widely used in literature. From the early 1990s, in part through the *U.S. Department of Defense Virtual Manufacturing Initiative* (U.S. Department of Defense, 2008), support has been delivered to develop virtual manufacturing terms and concepts. For the first half of the 1990s only a small number of major enterprises and a few academic research groups were actively involved in the field of virtual manufacturing (Banerjee and Zetu, 2001). Recently the use of virtual manufacturing has become increasingly prevalent, and a considerable volume of research has been carried

out on both the concept and construction of virtual manufacturing. This has become possible due to significant advances in computer and information technology, and has increased awareness of the great potential of virtual manufacturing.

So how can VM be defined? In simple terms, the word *virtual* refers to a concept applied in many fields and is defined as “*that which is not real but may display the full qualities of the real*”. The term *manufacturing* refers to all activities and processes involved in industrial product development. VM is often referred to as “*a computer system which is capable of using information technology to generate information about the state and behavior of a manufacturing process that can be observed in a real world manufacturing environment*” (Banerjee and Zetu, 2001), (Lee et al., 2001), (Iwata et al., 1997). A VM system provides a means of designing and evaluating manufacturing processes on-screen before actual facilities or products are constructed. In other words, VM is understood to be an integrated computer-based model which produces comprehensive information in order to analyze and understand real manufacturing system behavior. Onosato et al. (1993) and Lee et al. (2001) have described VM as a concept of simulating manufacturing processes with computers where operations can be evaluated before being implemented into the real world.

Similarly, Marinov (2000) has proposed a definition based on Norbert Wiener’s virtual manufacturing black box; the box contains the abstract prototypes of manufacturing models and the procedure of model exploitation is known as a computer simulation. Modeling and simulation are considered to be vital elements for virtual manufacturing. In recent years, with the emergence of Virtual Reality (VR) technology, many researchers have presented VM in association with VR, therefore an interesting question to ask would be: “*Is virtual reality a must in virtual manufacturing?*”. While Chetan et al. (1996) describe virtual manufacturing as a research area that aims to exploit Virtual Reality technology to

Figure 2. Virtual manufacturing



integrate the design sub-functions such as drafting, finite element analysis and prototyping with all the functions within a manufacturing enterprise, Lin et al. (1997) and Marinov (2000) consider VR only as a tool for visualization, which reinforces the graphical user interfaces for VM.

Clearly many approaches have been used for defining the virtual manufacturing concept. Amongst these an often referenced approach has been proposed by the Institute for Systems Research, University of Maryland, and is discussed in (Saadoun et al., 1999), (The Virtual Manufacturing User Workshop, 1994), and (Depince et al., 2004). According to these sources, virtual manufacturing is “an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control” (Figure 2).

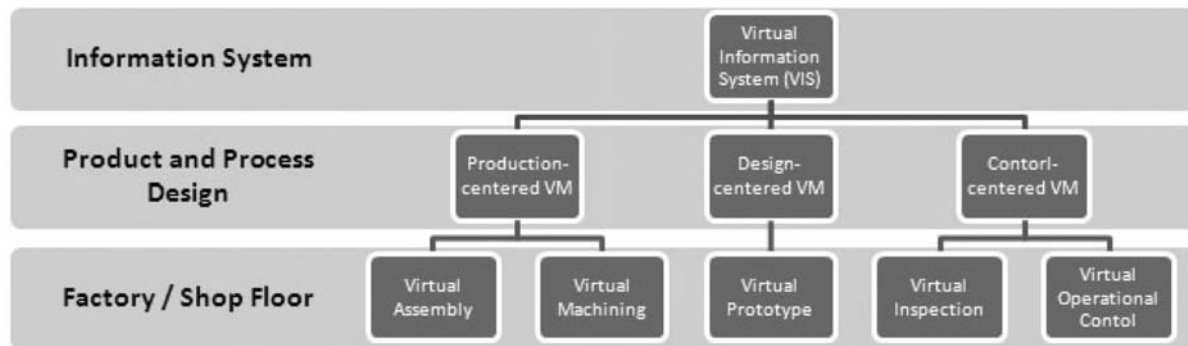
To summarize, from all of the above approaches it can be concluded that VM is “a knowledge and computer-based system technology that integrates the entire information of manufacturing processes, activities, and functions involved throughout the Product Life Cycle associated with virtual models and simulations instead of real facilities and manufacturing activities”.

A major outcome of virtual manufacturing is a Virtual Factory (VF). Again, many definitions and

research directions have been proposed by academics and manufacturing experts. For example, Jain et al. (2001) have developed a basic virtual model of a semi-conductor factory, demonstrating its functions in the design, installation and operation stages. The virtual factory integrates the simulation models of major sub-systems at all levels of hierarchy thus providing a vehicle for validation of integration.

Lin and Fu (2001) have proposed a virtual factory wherein a VR prototyping test bed allows the design of a detailed model to support system operations. The major goal of their prototype virtual factory is to define an operating procedure to capture the requirements of manufacturing engineers. A method for constructing large, rapid and complex virtual manufacturing environments has been developed by Xu et al. (2000), which provides the data link and user controls to enable streamlined data transfer between the virtual environments. Iqbal and Hashmi (2001) have developed a 3D virtual environment for design and analysis of a factory layout by applying problem-solving techniques. In their virtual factory approach, alternative layouts were compared and a new aisle system was introduced. Another factory layout planning problem has been studied

Figure 3. General scope of virtual manufacturing



by Kroves and Loftus (2000): an immersive VR interface was used in order to compare an immersive system with a monitor-based VR system for manufacturing workspace analysis. Wiendhal and Fiebig (2003) have also reported a virtual factory approach for modeling and cooperative planning of factories and production systems. They describe a digital factory for planning the manufacturing operations and processes for an industrial case study.

In summary, a Virtual Factory can be defined as “a complex computer based simulation system that provides the manufacturing system designer all the resources and tasks necessary to achieve the optimized operation of designing, producing and delivering a product” (Banerjee and Zetu, 2001).

THE SCOPE OF A VIRTUAL MANUFACTURING SYSTEM

The concept of virtual manufacturing can encompass the entire enterprise hierarchy. From the definition of Onosato and Iwata (1993), each manufacturing system comprises two sub-systems: a real information system and a physical system. Whilst the real information system is associated with the entire system’s architecture, manufacturing information activities and decision making within cost, weight,

investment, timing and quality constraint, the physical system comprises important units such as resources, machines, and parts. The scope of virtual manufacturing systems (VMS) can be subdivided into three levels (Figure 3): the information system, product and process design, and factory/shop floor.

In VM systems the simulation of the real information system, also called virtual information system, provides the necessary control commands for the virtual physical system (Lee et al., 2001, Iwata et al., 1997, Iwata et al., 1995). At virtual information system level the functional architecture of the manufacturing system is modeled, and covers all aspects directly related to the manufacturing of products. The product and process level of VM systems can be decomposed into design-centered, production-centered, and control-centered (Virtual Manufacturing User Workshop, 1994):

- Design-centered VM makes use of manufacturing-based simulations of different virtual designs to production prototypes in order to provide comparative information about the new product to the designer for use in optimizing the product design process.
- Production-centered VM uses simulation capability to simulate the activities in process development and alternative process plans. It aims to optimize the

manufacturing process by evaluating and validating the production plan, new processes and paradigms.

- Control-centered VM make use of VM technology to control models and actual processes, aiming to optimize the actual production cycle.

At the lowest level, virtual manufacturing includes not only modeling the items and facilities used for executing physical manufacturing activities, but also the simulation of their function throughout manufacturing processes such as Virtual Assembly, Virtual Machining, Virtual Prototyping, Virtual Inspection, and Virtual Operational Control (Lee et al., 2001). These simulated processes are developed independently from the other components of the virtual manufacturing system and possess individual interfaces to interact with.

VIRTUAL MANUFACTURING SYSTEM INFRASTRUCTURES

A Virtual Manufacturing System can be defined as a “*computer-based simulation of the entire manufacturing activities and processes*”. According to this definition, two core infrastructures of VMSs are *modeling*, which encompasses specifying what to model and at what level of abstraction, and *simulation*, which is the procedure of the model exploitation and provides manufacturing process attributes with certain degrees of accuracy and precision. Furthermore, Depince and Chablat (2004) have outlined the following infrastructures for comprehensive virtual manufacturing systems:

- **Manufacturing characterization:** includes capturing, measuring and analyzing the parameters that may affect material transformation during manufacturing.
- **Modeling and representation technologies:** different kinds of models for

representation, abstraction, standardization, multi-use, etc. are the major outcomes of such technologies. The same protocol and standard need to be created for manufacturing-related technologies to represent all the types of information associated with the process and product design in such a way that the information can be shared between all software applications, for example, knowledge-based systems, object-oriented, feature-based model, etc.

- **Visualization, environment construction technologies:** with recent advancements in computer graphics, the exploitation of Virtual Reality technology is more prevalent. The representation of information and manufacturing processes can be visualized in greater detail by the user in a way that is interactive and comprehensible.
- **Verification, validation and measurement:** all the results and decisions provided by virtual manufacturing systems need to be verified and validated.
- **Multi discipline optimization:** VM and simulation are used in combination with “traditional” manufacturing research.

VIRTUAL MANUFACTURING ENVIRONMENT APPLICATIONS

As discussed above, in virtual manufacturing the simulation environment created by computers is an artificial environment reflecting real physical objects and dynamic behavior. Advances in virtual reality technology have made it feasible to directly utilize VR for the modeling and realization of Virtual Manufacturing Environments. The use of virtual environments in simulating manufacturing environments gives engineers or trainers the opportunity to play a pro-active role in identifying flaws and optimizing any aspect of manufacturing-related processes and activities. The features of virtual environments provide an

important foundation of virtual manufacturing. Virtual Manufacturing Environment systems can be used in a wide variety of manufacturing systems contexts and have often been classified into several categories:

Product Design – 3D product design: For engineers who are involved in product design it is desirable to visualize the performance and the analysis of the design process throughout the development cycle. Virtual Environments provide the synthetic and expandable Virtual Manufacturing Environments for the designers in the conceptual design stage of a new product without the actual testing of the physical product. At this stage the functional experimentation of mechanical features can be performed to evaluate the conceptual design and any modifications can be made as required by the customers (Iqbal and Hashmi, 2001).

Product Design - Virtual Prototyping: Virtual prototyping is another application of VM in the product development design context. It provides the designer with important features of a product, which can be used before building the physical prototype, to prove design alternatives, to carry out engineering analysis, manufacturing planning, support management decisions, and to obtain feedback on a new product from prospective customers (Iqbal and Hashmi, 2001). In other words, virtual prototyping leads not only to the reduction in the fabrication of physical prototypes and product cost and time, but also supports product design presentation through qualitative simulation and analysis (Weyrsh and Drew, 1999).

Process and Production Planning: The potential of VM in process and production planning has been outlined by many researchers. Schaefer et al. (2001) state that optimal planning of a manufacturing system can be obtained by providing all those people involved in the planning process with a visual environment in which to monitor and compare the factors that may result in inadequate outcomes. Such a visual comparison can be performed based on the human experiences and

leads to rapid start-up of production and robust manufacturing processes.

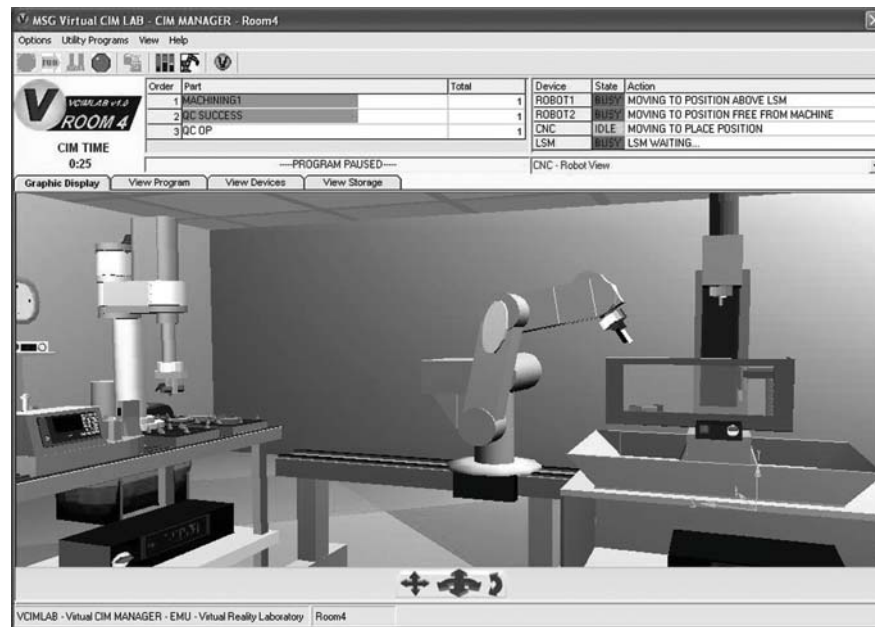
In addition, VM has been found useful by academic researchers and industry specialists for Computer Aided Process Planning (CAPP). For example, a VR-based CAPP system developed by Peng et al. (2000) allows users to create a 3D model of components from an original design, simulate the machining process based on existing NC code and pass the code to NC machines in the real world to create the real part. Thus any inconsistency in material and information flow can be detected and solved before being employed in practical manufacturing, which prevents costly mistakes (Maropoulos, 2003; Mujber et al., 2003).

Factory layout operation: *Virtual Machining* comprises of a virtual machining process and a virtual machining operation, and mainly involves cutting processes such as turning, drilling, milling, grinding, etc. In virtual machining, material removal processes and the relative motion between tool and work piece are simulated, and all the factors affecting machining setup time and processing time, quality and costs are studied. As a result, the feasibility of designed parts and selected processes for machining can be evaluated (Lee et al., 2001).

Virtual Assembly: Assembly is one of the most important stages in product development. In virtual assembly, the entire design and planning of the assembly process can be simulated in a 3D environment. Thus the assembly operation is verified and potential difficulties encountered in manufacturing are identified. Virtual assembly can benefit the manufacturer by saving time and costs in real production. Choi et al. (2002) suggest that virtual assembly can influence the efficacy of assembly, i.e., assembly methods, assembly sequence, and assembly time.

Virtual Inspection: Product inspection and measuring, specifically in machining operations, are time-consuming and require expensive physical experimentation. Virtual inspection is used to simulate both the inspection process and the

Figure 4. VR factory layout operations



physical and mechanical equipment. Yao et al. (2002) developed a test-bed in a 3-D environment for predicting surface roughness in virtual measuring and the topography of the machined surface of the virtual workspace.

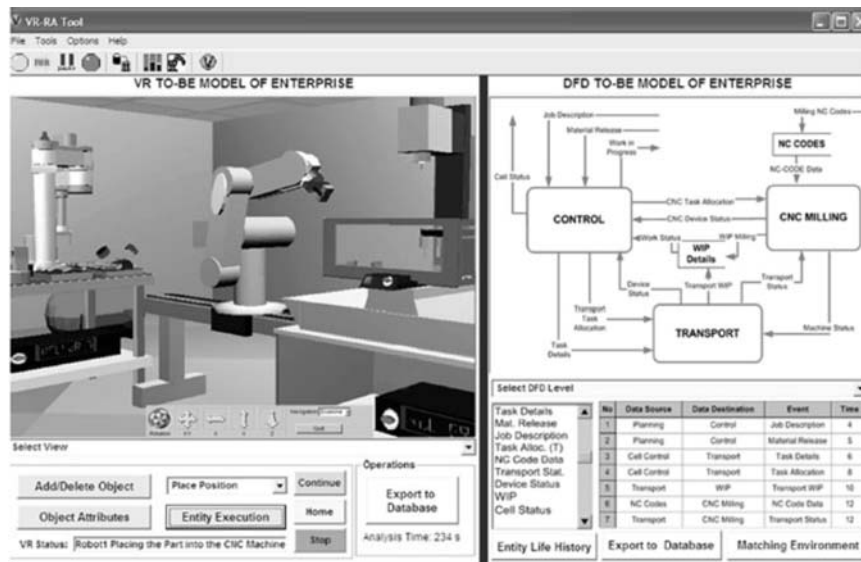
Virtual Operational Control: Material and information flow play an important role in the manufacturing system. Manesh et al. (2007) and Bal et al. (2008) developed a VMS based on a virtual environment for simulation of manufacturing material and information flow, which facilitated the simulation of the manufacturing activities in a more efficient and cost effective way, both prior to, and sometimes in parallel with, manufacturing operations in the real enterprise.

Virtual Agile Manufacturing: Bal et al. (2008) presented a Virtual Reality-based methodology for design of holonic-agile manufacturing systems. Their methodology uses VR for modeling, simulation and monitoring holonic manufacturing control systems and their operation. This allows users to interact intuitively with the manufacturing environments and its objects as if they were real, by immersing them in a highly realistic 3D

environment. As in the earlier step of developing and implementing the VR-based holonic design and operations of agile manufacturing systems, the concept and technologies were validated; the original objective was achieved, thus leading to further development and application.

Virtual Material Handling System: The application of a material-handling system (MHS) in a manufacturing environment aims to optimize productivity and improve equipment utilization and ergonomics. A virtual MHS enables the system designer to compare alternative material handling designs through a 3D environment in order to reduce the cost and increase the scalability and reliability of the system. It can also help the designer to identify and solve potential problems during design and operation to confirm the system model before constructing the actual enterprise. Furthermore, virtual material handling is widely exploited in controlling material handling systems such as Automated Guided Vehicles (AGVs). Wei and Chen (2002) have developed a virtual reality-based tele-autonomous for AGV path guidance. They have applied virtual reality

Figure 5. Virtual operational control



technology to establish a VR-based guidance system. In the developed system, AGV can be controlled through a more realistic and interactive 3-D environment by the operator. It was reported that this method provides better AGV guidance with less error.

VIRTUAL MANUFACTURING ENVIRONMENTS IN EDUCATION AND TRAINING

The efficient use of human skills, knowledge and experience is the major power of modern enabling technologies of agile manufacturing. A manufacturing enterprise needs skilled, cooperative and motivated people in order to achieve its goals. The participation of people throughout the enterprise in planning, designing and implementing new technologies and systems is the essential success factor. Hence, in the development of an agile manufacturing system, technical systems need to be designed not just to meet economic and technical goals, but also to satisfy organizational and human skills, judgment, creativity, knowledge,

and ingenuity, and to make full use of modern computer-based technologies.

Flexible Manufacturing Systems (FMS), automation equipment, robotic manufacturing lines, programmable systems such as Computer Numerical Control (CNC) machines and Automated Guided Vehicles (AGVs) are examples of systems that fit into the category of modern and computer-based technologies which improve manufacturing agility. However, the technologies that make these systems agile consist of highly expensive and complex systems, which involve potentially dangerous machinery and robots. Companies incur high costs in order to train their work force to use such systems and equipment.

In manufacturing education it is often desirable for engineers, technicians and even line managers to gain more practical experience in handling modern equipment and productions systems. However, it is time-consuming to learn how to use the fine controls of the equipment, as well as how to implement new manufacturing systems. Trainees have to be supervised while operating manufacturing equipment to avoid potentially expensive damage and large amounts of money have to be

invested to experience different production and manufacturing activities. To date many studies have shown that the use of computers in teaching and laboratory work is feasible, and has changed the economy of manufacturing education (Koh et al., 2002). It also has a positive impact on student motivation and appears to have similar educational effectiveness to 'hands-on' training.

The utilization of Virtual Environments in manufacturing education (Virtual Manufacturing Learning Environments) has been emphasized by many researchers, e.g., Youngblut (1997), Francis and Tan (1999). It has been shown that people can indeed learn to perform certain tasks such as console operation from virtual environments and that knowledge and skills acquired through a VR simulation can be effectively applied in the real world (Koh et al., 2002).

Virtual Reality in instruction utilizes computer models in order to simulate the behavior of a manufacturing system or process (Avouris et al., 2001). In this way it is possible to repeat an operation many times, comparing the findings with model-based values. In general, one can expect that the use of VE and other types of educational software in manufacturing training will provide a sufficient degree of interaction with the trainees. Their use also improves the overall quality of manufacturing-related education and offers a number of important advantages in terms of pedagogical value:

- Trainees devote their time to useful discussion and observations, have the opportunity to analyze results, repeat experiments, compare results with theory, etc.
- Trainees concentrate on understanding fundamental concepts and not performing tedious writing.
- Drilling can be enabled at any time without supplementary effort by the instructors.
- Minimization of failures due to incorrect parameters.
- Trainees can gain experience in manufacturing activities that usually require hours

or days to complete within a few hours or even minutes.

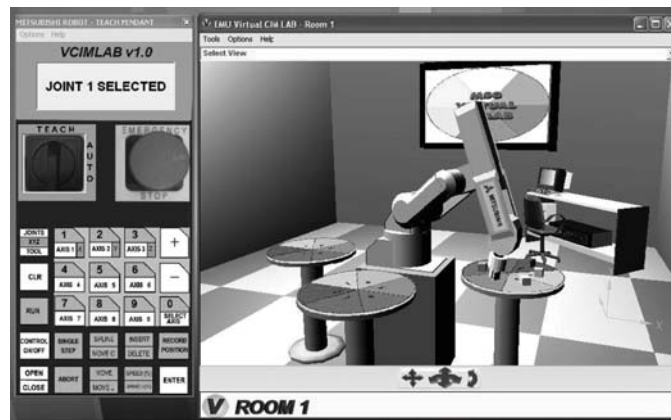
- Pace and complexity of education can be adjusted to suit individual experience.
- Any number of trainees can practice and be trained at any time.
- Trainees can be provided with a virtual tour, guidance, and assistance during the training.
- New possibilities for continuous education, distance learning, and collaboration with other industries in training (Avouris et al., 2001, El-Mounayri and Aw, 2005, Sunrise, 2008).

The various applications of Virtual Environments in manufacturing which were outlined in the previous section can be effectively utilized in manufacturing education. One of its most important applications is for training in operating manufacturing equipment such as machining equipment and robots. It is generally accepted that training on real machines includes disadvantages such as:

- High costs because of system down times.
- Fixed site for the training.
- Hazards for trainees and instructors.

CNC machines are one of the most widely used pieces of machining equipment in the manufacturing industry. Due to their high cost and complexity it is often difficult for companies to keep up with the rapid developments in equipment. The same applies to training of the workforce. Traditionally, the user needs to work through operation manuals and then follow the instructions to practice and learn how to use the equipment. The user may also ask an experienced worker for help, however lengthy explanations are time consuming and ineffective. A new user may make many mistakes while operating the real machine in the initial stage of familiarization. In addition, limited availability of facilities and personnel can make

Figure 6. Virtual robot control



it difficult to train large numbers of trainees for any given machine.

Taking all these problems into account there is an increasing desire to adopt a new education paradigm known as Virtual Reality Based Training and Education in order to make training safer, more economic and effective. Users acquire the same experience and basic operational knowledge using VR-based training for CNC machines as they would using the actual machine. More importantly, it will be safer and more economic to practice on a virtual CNC machine rather than on the real machine.

The use of robots is another manufacturing equipment operation which is categorized as being potentially dangerous, as well as expensive if damaged. In addition, robots are time consuming and difficult to use, and trainees have to be supervised when operating such machinery. To overcome these problems, virtual robots are widely used in education and training for programming and operation purposes. The user can write an off-line task program and then use the virtual robot for teaching trainees to control of its movement in a virtual environment, as well as storing the robot positions into its memory.

Manufacturing systems are complex. In order to design an effective and efficient system, manufacturing system requirement analysis and

information modeling are required. Therefore, a *user concept diagram* which contains icons rather than data flow bubbles or boxes for representing the actual physical system is proposed. Billo et al. (1994) state that most trainees, and even users, find diagrams too abstract to understand the system, and difficult to modify and apply to another manufacturing system. A virtual environment constitutes an effective communication means since it is constructed from images which correspond to their real counterparts. Hashemipour et al. (2009) reported that the VE assists the trainees in the modeling and analyzing of the relationship between the material and information flows. Virtual reality-based requirement analysis promotes modeling and understanding of complex systems and reduces the costs and time involved at this stage by producing precise and accurate specification requirements for plans and designs for manufacturing systems. In addition, it allows the users to interact intuitively with the virtual environment and its objects as if they were real, by immersing them in a highly realistic 3D environment.

Inspection is one of the major factors that affects the quality of the finished product. In *virtual inspection* the trainee engineer can practice all the inspection procedures, operations and skills in a completely safe and interactive 3D environment.

In *virtual assembly environments* engineers and trainees are to be trained to investigate the feasibility of different assembly processes based on certain production constraints. Such training enables engineers to optimize the assembly process in response to the rapid change of product types and markets.

In summary, virtual environments provide excellent training opportunities for manufacturing by allowing each employee full access to the entire facility. The virtual environment enables trainees to practice new and existing tasks in a safe, controlled environment. They will be able to see how a product takes shape as it moves through the manufacturing systems, which result in more effective training (Wang and Li, 2004).

KEY DIFFERENCES BETWEEN HIGHER EDUCATION AND CORPORATE EDUCATION

It is widely accepted that each society's broad mission is to provide a skilled work force so that it can build and maintain the productivity of any given industry. Higher education and corporate education are recognized to have an important role in achieving this mission and are equally important to society.

Higher and corporate education are related by different pursuits. Both deliver knowledge and concepts specific to their respective sectors. Higher education encourages analytical thinking which contributes to contribute to the professional and intellectual development of the student. Corporate education delivers practical knowledge, skills and techniques. Many studies have shown that the higher education sector requires up-to-date resources, together with rapid technological advancements, in order to meet the needs of the labor market and industry for high-level user skills (Hashemipour, 2009). In order to fulfill such requirements, higher education needs a major investment in terms of capital and

manpower; unfortunately, a shortage of resources could undermine the facilitation of a quality learning environment.

Although some higher education institutions have adopted new educational resources, such as VLEs, to cope with rapid technological changes and to provide students with opportunities to use the latest equipment and technologies during their university education, there is still a gap between industry needs and higher education's output. This is due to the fact that educational institutions are usually more concerned with meeting the requirements of the university with regard to curriculum design and academic content of courses rather than industrial needs.

For the corporate sector to achieve growth, innovation and sustained competitiveness, learning is the most fundamental of the dynamic capabilities (Teece et al., 1997). An essential distinction needs to be made between aspects of learning for an individual in the corporate sector and an individual in the higher education sector. Relentless competitive pressure makes the corporate sector increase the productivity of all resources in the short term, and may be emphasizing short-term needs which could be at different levels, or in different geographic places. However, an individual in the higher education sector may spend several years acquiring knowledge which may no longer be relevant in the future. In other words, change demands continuous development of an individual's knowledge beyond higher education.

The importance of investment in corporate education is justified by a number of studies, e.g., (Paton et al., 2005, Becker, 1964). Major outcomes of corporate education are:

- Boosting individual job performance.
- Providing competent employees at low cost.
- A growing link between business performance and workforce skills.
- Providing advice and assistance to the industry on skill development.

- Meeting the demands of both the market and specific technologies.

SYNERGY BETWEEN VIRTUAL LEARNING ENVIRONMENT AND CORPORATE EDUCATION

Over the past decade, the rapid developments and growth of Information Technology (IT) have exposed a new paradigm for educational technology research and development in a wide range of subject areas and at all levels. Exploiting information and computer technology as teaching and learning tools provides such a learning environment. The so-called Virtual Learning Environment (VLE) overcomes the limits of space and time in knowledge delivery and utilization, along with allowing trainees to determine their own learning path and pace. Studies have shown that VLEs offer a number of advantages over traditional teaching environment in terms of knowledge acquisition, convenience and flexibility (Carrillo, 2004).

VLEs are simply defined as “*computer-based environments that are relatively open systems*” (Wooldridge, 1999). They are capable of supplementing traditional face-to-face teaching methods and normally work over the Internet. A significant body of literature demonstrates how VLEs can be an effective means of enhancing, motivating and stimulating the trainee’s understanding of learning material, as well as reducing educational cost (Xa et al., Pan et al., 2006).

Despite all the VLE advantages, it is not always effective and sometimes fails to meet the learning objectives. Xa et al. (2006) reported insufficient interactivity and dynamism as one of its major limitations. One potential approach to overcome these limitations is the utilization of Virtual Reality (VR) technology. VR interfaces are capable of being used to complement existing VLE approaches in education (Pan et al., 2006). Recent advances in computer technology, networking, and advent

of the World-Wide-Web allows Web-based distributed Virtual Environments to be created that are available from any Internet-enabled computer. Distributed Virtual Environments have been used in a wide variety of educational settings of different types.

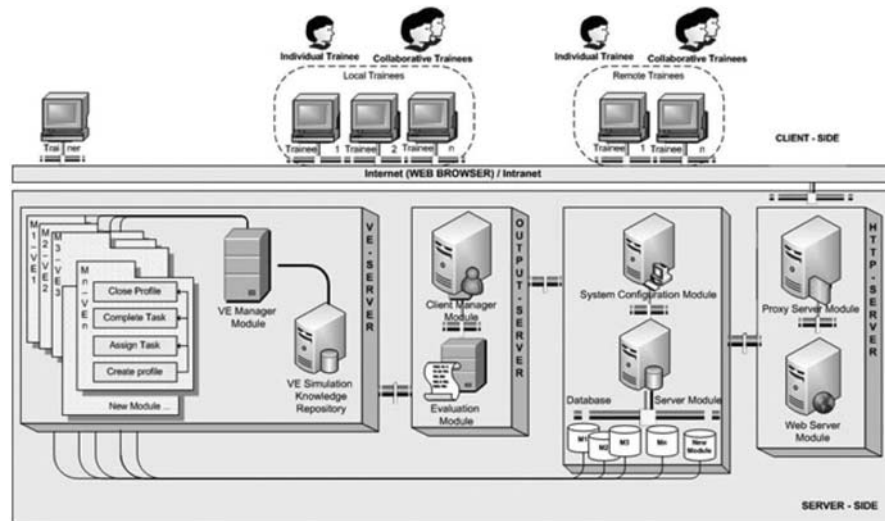
Integrating VLE with Virtual Environments provides an immersive, interactive and flexible Virtual Learning Environment where learners, especially distributed ones, can share information and form the environment according to their needs (Prasolova-Førland, 2008). Such educational environments can actively involve the trainee in the learning process, which in turn facilitates deep learning, improves learning quality and reduces educational costs.

Though lacking immersion factor, the power of VLEs in the global learning market is demonstrated by a report from Ambient Insight (2007). In 2007 the approximate value of the global market for E-learning products and services (VLEs) was \$17 billion. This total is forecasted to rise to \$50 billion by 2010, which implies that the market will expand in the near future by applying VR/VE potential into VLE (Pan et al., 2006).

With rapid globalization the emerging technologies are currently being developed faster, as well as more efficiently and at lower cost, in places beyond their origin. One consequence is that many industries, in particular manufacturing industries, are not only outsourcing manufacturing, but also research and development sections. This course of action is resulting in the need to keep their workforce both familiar with the latest manufacturing-related technologies and trained in utilizing state-of-the-art equipment. This implies that access to education is crucial for the success of manufacturing industries.

The authors propose a system architecture for corporate manufacturing education utilizing virtual reality technology to assist learners in improving individual skills or collaborate with other learners through a realistic virtual environment for

Figure 7. Proposed VLE/VE system architecture



the realization of the VLE/VE system. A Modular Client/Server approach has been chosen, which provides the the following features:

- Multi-user and multi-screen is inherent to the client/server approach.
- Discrete event simulators are easily compatible.
- The modular structure of the system allows the trainers and trainees to alternate the training material configuration and input parameters to contribute to the design of further practice.
- Modules can take advantage of the distributed nature of a client-server environment.
- All modules can be categorized as either independent or collaborative.
- Develops clients' understanding of their working practice either individually or in a group.

An overall architecture of a VLE/VE system is shown in Figure 7.

The Client-side refers to operations which are performed by clients. In the proposed system, the client is categorized into 'trainer' and 'trainees'.

All the operations such as processing, storage of data from clients, managing, reconfiguring, etc. are performed by the server side. The server side includes the VE-server, Output-sever, HTTP-Server, Database-Server, and system configuration module.

VE-server: the VE-manager is the central component of the VE-server. Its main task is to coordinate the work of different VE modules. The VE-manager collects the information from all modules and corresponding clients and stores this in a VE simulation knowledge repository.

HTTP-server: is responsible for accepting requests from clients through web browsers and establishing the safe communication between server-side and client-side by proxy server and web server modules.

System configuration module: allows clients to access each module through different work stations and reconfigures the whole system after new modules have been added or modified by defining a set of configurations in a file.

Database server module: stores all information regarding clients and system settings, and also manages access to all shared data in the program.

Output-server: comprises a client manager and evaluation modules. Scheduling, defining the level of difficulty and assigning a client's relationship are carried out by the client manager. In addition, the client manager allows trainees to dynamically load modules through an interface by specifying their execution features such as profile, assigned task, scheduling, and completed tasks. The Evaluation Module provides a two-way feedback mechanism for each module completed. Trainees provide details of the procedures followed, results obtained, their analysis and conclusions and receive a module report. In addition, trainees can complete a questionnaire regarding bugs, usability and effectiveness of the module materials for their learning.

CONCLUSION

The focus of this chapter is the use of Virtual Learning Environments as an important and strategic means to facilitate future corporate education initiatives. VLEs are one of the most promising methods of delivering safe, cost-effective, convenient and flexible learning to supplement traditional teaching and offer an effective means of enhancing the learning process.

A review of existing virtual technologies is provided and a number of VE applications in manufacturing-related education and training have been highlighted. Guidelines for the development and implementation of such a system in distributed corporate settings have been proposed.

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KEY TERMS AND DEFINITIONS

Virtual Reality: "Virtual Reality is a way for humans to visualize, manipulate and interact with computers and extremely complex data." (Aukstakalnis and Blatner, 1992). "A computer system used to create an artificial world in which the user has the impression of being in that world and with the ability to navigate through the world and manipulate objects in the world" (Manetta and Blade, 1995).

Virtual Environment: A computer graphic system that allows a user to act in a synthetic, computer generated interactive 3D world.

Virtual Manufacturing: "A computer system which is capable of using information technology to generate information about the state and behavior of a manufacturing process that can be observed in a real world manufacturing environment" (Banerjee and Zetu, 2001), (Lee et al., 2001), (Iwata et al., 1997). "An integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control" (Saadoun et al., 1999; Virtual Manufacturing User Workshop, 1994; and (Depince et al., 2004). A knowledge and computer based system technology that integrates the entire information of manufacturing processes, activities, and functions involved throughout the Product Life Cycle associated with virtual models and simulations instead of real facilities and manufacturing activities".

Virtual Factory: A Virtual Factory can be defined as "a complex computer based simulation system that provides the manufacturing system designer all the resources and tasks necessary to achieve the optimized operation of designing, producing and delivering a product" (Banerjee and Zetu, 2001).u